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ABSTRACT

Title of Thesis: The relationship between social discomfort and executive functioning.

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Introversion and behavioral inhibition are stable individual characteristics associated with an overaroused central nervous system and have been associated with relative executive functioning deficits. The specific relationship between non-clinical levels of social anxiety and executive functioning has yet to be evaluated. The present study evaluated these factors in 29 high-functioning, psychiatrically normal volunteers using three tests of both simple and complex executive functioning. Using a multivariate regression analysis with ethnicity, education, intelligence and simple task performance controlled for, higher levels of self-reported social discomfort were associated with poorer scores on Part B of the Trail Making Test and the Color-Word task of the Stroop Neuropsychological Screening Test. No such relationship was found on the Digit Span task. These results have implications for further understanding of shared neurobiological mechanisms underlying social discomfort and executive functioning.

THE RELATIONSHIP BETWEEN SOCIAL DISCOMFORT

AND EXECUTIVE FUNCTIONING

By

Lieutenant

John R. Ashburn Jr.

U.S. Navy Medical Service Corps

Master's Thesis submitted to the faculty of the Department
of Medical and Clinical Psychology
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TABLE OF CONTENTS

LIST OF TABLES

Appendix B:

1. Introduction

The present study examines whether individuals characterized with high levels of social discomfort demonstrate impaired neurocognitive processing. There is tentative evidence that high social discomfort is related to underlying neurophysiological mechanisms and that social discomfort can be construed as a psychological trait. Social inhibition is characterized by behavioral inhibition (defined as high reactivity to novel social stimuli; Kagan, 1989). Because of the conceptual overlap between constructs such as social discomfort, behavioral inhibition, introversion, social phobia, and general anxiety, the divergent validity of these constructs and their interrelationships will be explored in this Thesis.

In the subsequent sections the following issues will be addressed: (1) background on personality and temperament models relevant to social discomfort; (2) the neural basis of personality and temperament; (3) cognitive processing and personality/temperament; (4) automatic and controlled processing relevant to the investigation of social discomfort; (5) tests of automatic and controlled processing (executive function and central executive working memory); and (6) an introduction to design of the present study. The remainder of the thesis describes the methods used, results, and concludes with a discussion of the research findings and study limitations.

1.1 Background on personality models and temperament

The nature of 'personality' and related constructs have long interested psychologists and has been a central component of their efforts to better understand the complex individual factors that contribute to behavior. A variety of rational, theoretical and empirical approaches have been developed throughout the years to examine personality, temperament, and related behaviors. While previous researchers have been limited to speculating via proxy measures the proposed neural factors impacting personality approaches to examine these issues, current researchers have the tools (e.g., functional neuroimaging (fMRI)) to examine specific brain/behavior relationships. Furthermore, these new technologies are shedding light on the relationship between individual differences in performance on cognitive tasks and personality factors. This is allowing us to investigate the neuropsysiological basis of behavior more directly. However, for the most part, we still primarily must rely on the definitions of the constructs of personality and temperament for which a neurophysiological basis is the foundation.

1.1.1 Definitions and models: Personality and temperament

Because of the potential ambiguity of terms such as 'personality' and 'temperament' the following operationalizations of these terms are offered. Gordon Allport (1961) proffered the following definition of personality:

> Personality is a dynamic organization, inside the person, of psychophysical systems that create the person's characteristic patterns of behavior, thoughts, and feelings.

As for temperament, John Bates (1989) wrote that it could be defined as:

> biologically rooted individual differences in behavioral tendencies that are present early in life and are relatively stable across various kinds of situations and over the course of time…

While the two preceding constructs are obviously not one and the same, it seems apparent that personality and temperament can overlap substantially (perhaps hierarchically, with temperament at the top) and that those patterns of behaviors characterizing certain personality traits could derive from common underlying biological substrates (i.e., certain temperamental profiles).

A variety of models of personality have been promulgated. Currently, the most prominent personality model is a 'Big 5' model (Costa & McCrae, 1985). Also quite prominent in the personality literature is the 'Big 3' model (H. Eysenck, 1992). The Big 5 model, also known as the five-factor model (FFM), is based on a lexical approach (i.e., personality is encoded in language) while the Big 3 model, also known as the Psychoticism/Extraversion/Neuroticism (PEN) model, is based on a biological model of personality (H. Eysenck, 1992). The two models overlap substantially. For example, the Extraversion dimension of both models is characterized by the factors of sociability, activity, and expressiveness. The Neuroticism dimension is also very similar in both models (generally characterized by high negative emotionality).

For the purposes of this study, a Big 3 conceptualization of personality is adopted to examine the relationship between social discomfort and complex executive functioning. This choice is for both theoretical as well as practical reasons. Theoretically, the Big 3 model is rooted in biology and, in this study, underlying differences in neuro – psychophysiology are postulated to underlie differences in both a personality construct as well as performance on a complex cognitive task. Practically, much of the individual difference neuroimaging and psychophysiological data that is available has been conducted using the Big 3 taxonomy (perhaps because of the proposed biological substrates), making generalizations to the Big 5 model potentially hazardous. Moreover, the individual difference predictor variable available for this study is a more general measure of social anxiety and fits more parsimoniously into the Extraversion factor of the Big 3 model vice the Big 5 model, for which each factor is more constrained and/or circumscribed.

1.2 Evidence of the neural basis of introversion and extraversion

Important within the Big 3 conceptualization of personality are the various biological correlates of the different personality and temperament dimensions. While some of the data on this topic comes directly from the individual difference literature, some of it comes from research in the temperament arena. Two important researchers who have investigated the neural underpinnings of personality and temperament are Hans Eysenck and Jerome Kagan.

1.2.1 Eysenck's extraversion dimension

For the purposes of this study, as well as historical purposes, it is important to understand the Extraversion dimension of the Big 3 model (H. Eysenck, 1967). It is based on the work of Hans Eysenck; in his personality conceptualization, the Extraversion dimension is a fairly stable construct concerning tendencies towards sociability, expressiveness, activeness, responsiveness, and dominance (H. Eysenck, 1967). The opposite pole, represented by introversion, is a stable characteristic that is driven more by internal personal reflection and a tendency to avoid external stimulation (especially social stimulation). Importantly, Eysenck postulated that the resting, steady-state level of ascending reticular activating system (ARAS) activity in an individual would reflect their placement on the Extraversion dimension of personality (H. Eysenck, 1981), thus reflecting a biologically-mediated mechanism for this personality dimension. More specifically, he proposed that introverts would have increased levels of ARAS activity (and correspondingly increased levels of cortical arousal) at rest when compared to extraverts.

1.2.2 Kagan's behavioral inhibition model of temperament

Eysenck's theoretical framework focused on the underlying neurobiological mechanisms associated with identified personality characteristics in adults. Of additional importance in establishing the validity of a personality dimension as representing a stable trait is the longitudinal stability of that trait across human development. The work of Jerome Kagan and colleagues (e.g., Garcia-Coll, Kagan, & Reznick, 1984; Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984; Kagan, Reznick, & Snidman, 1987; Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988; Reznick, Gibbons, Johnson, & McDonough,1986) provides the richest vein of data for examining both the level to which temperament is biological in nature and the degree to which it is stable throughout individual development.

The specific aspect of temperament in which Kagan has been interested has involved what he describes as "behavioral inhibition", operationally defined as specific tendencies first identified in early childhood to produce exaggerated behavioral responses to unfamiliar people and objects (Kagan & Moss, 1962). Kagan found that behavioral inhibition was the "only psychological quality preserved from the first three years of life through adulthood…." (Kagan, 1989). The behavioral inhibition temperament of exaggerated response to novelty represents a behavioral manifestation of overarousal, the defining characteristic of the introversion pole of Eysenck's Extroversion personality domain.

The primary research from which Kagan derived his data and conclusions involved two independent cohorts, both of which were initiated during early childhood (at 21 months and 31 months of age, respectively) and which included longitudinal follow-up time points (at 5.5 years and 7.5 years, respectively). An additional follow-up was conducted with one cohort when the participants were approximately 13 years of age.

The most important findings in this research involves the degree to which the infant's initial behavioral tendency was preserved over time, the degree to which those with the different classifications (behaviorally inhibited versus uninhibited) varied on measures of anxiety and behavioral restraint, and differences between the two extreme groups on various physiological variables (thus reflecting underlying neurobiological mechanisms) (Kagan, 1989).

Regarding the stability of the inhibited behavioral tendencies (based on the initial classification), approximately 75% of the subjects overall retained their original status at the third follow-up visit (7.5 years old; $r = .67$ for Cohort 1, and $r = .39$ for Cohort 2, $p < .001$ and $p < .01$, respectively; Kagan et al., 1984). Quantitative differences in measures of behavioral restraint and anxiety were found between the two extreme groups at the later follow-up visits. For example, when asked to allow themselves to free fall backward onto a mattress, significantly more inhibited then uninhibited children folded their bodies back into a sitting position or simply failed to comply with the request at all (Kagan, 1989). In relation to anxiety, at age 7.5 years almost 75% of the children originally categorized as behaviorally inhibited demonstrated one or more unusual fears (such as attending summer camp, remaining alone in the home, or going to the bedroom alone at night) while only 25% of the previously categorized uninhibited children demonstrated such fears (Kagan et al., 1984).

Differences between the two extreme behavioral inhibition groups were also found on various physiological measures, with greater activation of arousal-mediated physiological systems in the stable resting state found in the inhibited compared to the uninhibited group (Kagan, Reznick, & Snidman, 1987). For example, at every follow-up age that was examined, the extreme inhibited group was found to show mild cardiac acceleration (usually about 10 beats per minute) to multiple trials of individual tests, as well as to the entire battery of tests. This finding suggests greater sympathetic influence on the cardiovascular system of those in the inhibited group as compared to the uninhibited group, and is conceptually similar (despite implicating different physiological systems) to the overarousal characterizing the introversion pole of the Extraversion dimension. In addition, higher levels of morning cortisol were found in the inhibited group, suggesting involvement of the Hypothalamic-Pituitary-Adrenal axis. Lastly, an aggregate of 8 peripheral psychophysiological variables showed a substantial positive relation with behavioral inhibition and, importantly, was maintained over time (r = .70 at 21 months, r = .64 at 7.5 years) (Kagan, Reznick, & Snidman, 1987).

The empirical evidence for physiological differences between the inhibited and uninhibited groups is essential, as it would be expected that biologically-based differences in temperament would result not only in different behavioral responses but in different physiological profiles as well. Such differences in physiological profiles have also been reported in other biologically-orientated individual difference studies (Rothbart

& Posner, 1985). Kagan hypothesized that the observed behavioral differences between the two extreme behavioral inhibition groups derived from different thresholds of affective reactivity between the groups, based primarily in the amygdala and hypothalamus (Kagan, 1989). This is consistent with the previously stated position that behaviors associated with personality traits may have a biologically-mediated etiology.

In addition to the longitudinal stability of behavioral, affective, and neurobiological features of behavioral inhibition tendencies, there is also evidence that the extreme characterization of behavioral inhibition in childhood has direct implications for differences in later clinical psychopathology. For example, seventy-nine 13-year-olds who were originally classified by Kagan's group as either inhibited or uninhibited in their second year of life were later interviewed by an independent investigator (Carl Schwartz). In these subjects, 61% of the inhibited versus only 27% of the uninhibited adolescents evidenced symptoms of generalized social anxiety (Schwartz, Snidman & Kagan, 1999).

1.2.3 Summary: Personality models and temperament

The background on personality and temperament makes clear that individual differences in social interaction behaviors exist, that one dimension of these differences may relate to 'anxiety' (loosely termed and as manifested by levels of sociability and behavioral inhibition), that these behaviors demonstrate some degree of temporal stability, and suggests that these differences are biologically-mediated. If this were true, it would be expected that the advent of tools like the electroencephalogram (EEG) and neuroimaging would help to more clearly delineate the relationship between personality, anxiety, and specific brain areas/activities.

1.3 Differences in introversion and extraversion: Evidence based on neurophysiological data

Although somewhat limited, the neuroimaging and EEG data that have involved individual difference variables have buttressed the argument for different underlying neurophysiological mechanisms across these different variables. Note that, unlike the previously presented data on behavioral inhibition, these studies are cross-sectional. Hence, no inferences regarding causality can be made. It could very well be that these biological differences as well as personality/temperament reflect a common, unidentified third factor.

1.3.1 Evidence based on neuroimaging data

The neuroimaging data have indicated differences between extraverts and introverts in areas of brain activity. For example, one positron emission tomography (PET) study (Fisher, Wik & Fredrikson, 1997) demonstrated that in comparison with extroverts, introverts show greater subcortical activation of the basal ganglia. More specifically, left-lateralized increases in putamen activity were observed in the introverted group. This finding fits with existing models of the Extraversion dimension and related behavioral sequlae. As noted by Fisher et al., introverts have demonstrated superiority to extraverts in vigilance tasks (where the subject has to engage in some sort of sensory signal detection interspersed with long periods of inactivity), and the basal ganglia has been implicated in vigilance tasks. The basal ganglia is also considered to encapsulate the limbic system (Martin, 1996) and parts of the limbic system have been implicated in behavioral inhibition (Kagan, 1989).

In a recent functional magnetic resonance imaging (fMRI) study comparing introverts and extraverts, introverts demonstrated an increased number of cortical areas activated, as well as having increased blood flow in the frontal lobes and the anterior thalamus (Johnson et al., 1999). This is consistent with the previous information presented on the Extraversion dimension in that introverts are thought to demonstrate higher overall cortical activity than extraverts. The findings also fit the neurobiological personality model of Jeffrey Gray (Gray, 1991), who proposed that extraverts have lower than normal activity in areas associated with what he called the behavioral inhibition system (BIS), including the frontal lobes and the hippocampus.

Neuroimaging has also shed light more directly on the relationship between brain activation and anxiety. One such study, using fMRI, was designed to examine the neurobiological correlates of aversive classical conditioning in normals and social phobic patients, with the hypothesis that there would be a between-group difference in those areas of the brain activated during some part of the habituation, acquisition and extinction trials (Schneider et al., 1999). This study found that, during the acquisition phase of the trials, the social phobic group demonstrated increased activation in the amygdala and the hippocampus. These structures are adjacently located in the limbic area and, based on their known function(s), their activation can have implications for affect, cognition and behaviors.

Another neuroimaging study, using regional cerebral blood flow (rCBF) technology, examined the neurophysiological changes over treatment (both pharmacologic and psychotherapeutic) in a group of social phobics (Furmark et al., 2002). Regardless of treatment modality, those subjects classified as responders demonstrated decreased activation in the amygdala and hippocampus (along with adjacent cortices) in response to an anxiogenic public speaking task. The authors concluded that social anxiety is related to the overactivation of those areas of the brain (e.g. the limbic system) that subserve physical defense mechanisms to perceived threat.

1.3.2 Evidence based on EEG data

The role of biological factors associated with temperamental differences also has been supported by electroencephalogram (EEG) studies of infants and children, represented prominently by the work of Fox and Calkins (Calkins & Fox, 1992; Fox, 1989; Stifter & Fox, 1990). In EEG research, the area of interest lies in the pattern of activation between the right and left hemispheres. A net difference in activation between the two hemispheres is calculated, and the interpretation is based on the assumption that the suppression of power in a particular frequency band reflects activation in that band as well as that hemisphere. For example, when approach behaviors are elicited there is greater left frontal activation (greater power suppression in the EEG over the left frontal region), and when withdrawal behaviors are elicited, greater relative right frontal activation is found (Fox & Davidson, 1986). In infancy, these EEG findings are thought to reflect subcortical asymmetries (possibly located in the amygdala, which is also implicated in Kagan's behavioral inhibition construct), a limbic structure which is involved in fear conditioning and emotional responses and which has direct connections to the anterior frontal regions of the cortex.

In one recent study (Fox et al., 1994) a group of 4-year olds were observed in a same-gender play quartet. Their behaviors were coded using Rubin's Play Observation Scale and measures of inhibited behavior, social competence, and compliance were calculated. In a separate session, the children had their EEG recorded and the relationships between left and right frontal power and sociability and inhibition were analyzed. As expected, children who exhibited high degrees of sociability displayed increased left frontal activation, whereas those who displayed increased inhibition (absence of approach behaviors) demonstrated increased left frontal hypoactivation.

In a related EEG study, a group of 4-month olds infants who were selected for high motor activity and high negative affect exhibited greater relative right frontal activation while those selected for high motor activity and high positive affect exhibited higher left frontal activation (Calkins & Fox, 1995). Importantly, Calkins and Fox were guided in their assessment of the infants by the work of Kagan and believe that their EEG findings reflect underlying neurophsyiological processes (such as overactivity in the amygdala) that directly correspond to the behavioral manifestations of behavioral inhibition (Calkins & Fox, 1995).

In terms of temporal stability, it has been found longitudinally that correlations for EEG power are relatively low (approximately .4) but significant (Fox, Bell, & Jones, 1992). However, this methodology is complicated by the fact that as a child develops there is an increase in power of the higher frequencies bands, and that correlations for EEG asymmetries are higher in behaviorally selected groups (e.g. high motor activity-high positive affect) than in the general population (Reznick, Gibbons, Johnson, & McDonough, 1989).

1.3.3 Summary: Neural basis of personality and temperament

Based on the preceding findings, it is apparent that there are specific areas of the brain whose activity correlates with the personality construct of introversion and the temperamental construct of behavioral inhibition and that these constructs demonstrate some stability over time. Furthermore, these same brain areas appear to be related to social anxiety and general avoidance behaviors in social situations. The stability of the symptoms of social anxiety has obvious repercussions for ongoing emotional and psychosocial development (e.g., impact on developmental learning history). However, in addition to the impact on psychosocial functioning, because the behaviorally inhibited temperament has been shown to be associated with specific neurophsyiological/cortical and subcortical regions this temperamental feature may also be expected to impact cognitive processing operations.

1.4 Cognitive processing: Interference and introversion/extraversion

Cognitive interference, broadly defined as "thoughts that detract from on-task activity" (Yee & Vaughan, 1996), has generally been found to have a strong relationship to anxiety. For example, individuals who score high in measures of trait anxiety have been found to be excessively prone to experience high levels of cognitive interference on objective information processing measures (Zarantonello, Slaymaker, Johnson & Petzel, 1984). Furthermore, differences in the extraversion dimension (ostensibly correlated with differences with anxiety, specifically social anxiety) have been found to impact specific domains of cognitive processing, indicating the possibility of a relationship between extraversion and cognitive interference. One model that attempts to account for the individual differences aspects of the interfering effects of anxiety on cognitive processing is represented by the work of Lieberman (2000) in the area of Cognitive Busyness.

1.4.1 Understanding the relationship between introversion, extraversion and cognitive performance: Cognitive busyness

Cognitive busyness is a construct from the social psychology literature that has been used to describe the ratio of cognitive resources being used during the processing of social interactions compared to the total resources available (Gilbert, Pelham & Krull, 1988). Testing of cognitive busyness and the available resources usually involves an experimental dual-task procedure in which the subject is made to work on several cognitively demanding tasks simultaneously or to have some resource-intensive task (e.g. serial number recitation) superimposed on an existing social perception task (Gilbert & Hixon, 1991).

According to the social interaction model, cognitive busyness represents the dual-processing that occurs within social interactions. During social interactions the social perceiver is "busy" actively processing socially-relevant information (nonverbal cues) beyond the specific verbal interchange and manipulating that additional information to self-modulate socially-relevant behavior(s). Thus, active processing during social interactions involves higher-order executive processing functions characterized as cognitive busyness. This utilization of additional cognitive resources during social interactions are reflected by a reduction in performance on a single target task when it is administered in a dual-task procedure (Gilbert & Hixon, 1991). Lieberman (2000) extended the cognitive busyness model of normal social interactions to explain information-processing differences between individuals at the extremes of the Extroversion personality domain.

In order to examine Lieberman's model, it is first important to understand the defining features of "executive functioning" and the nature of the tasks that have been used to demonstrate these features. Executive functions are those cognitive processing operations associated with prefrontal brain regions that manage the integration and organization of basic cognitive processes for planning, organizing, initiating, revising, and monitoring complex thoughts and behavior (Lezak, 1995). The executive functioning task in Lieberman's research is generally characterized as a measure of executive working memory function and has been described in terms of one component of a larger working memory model (Baddeley, 1986). According to the model proposed by Baddeley (1986) the complete working memory model consists of three discrete subsystems: the central executive, the phonological loop and the visuospatial sketchpad (see Figure 1).

Insert Figure 1 about here

The central executive component of working memory is reflected by cognitive processing tasks that require holding information in passive mental stores while concurrently actively processing and manipulating the material mentally to produce a new response (Baddeley, 1986).

Based on this model, the central executive subsystem represents the dynamic component of working memory. Here, information is actively manipulated. The other passive 'slave' systems (i.e., the phonological loop and visuospatial sketchpad) receive their information for passive storage through the central executive subsystem. The phonological loop is the component of the working memory system responsible for short-term auditory verbal memory. The visuospatial sketchpad is that part of short-term memory used for holding image traces and visual memory reproduction. Thus, both of these slave systems are passive holders of data while the central executive engages in more active processing and manipulating of the data (Baddeley, 1986).

The role of the central executive in the active manipulation of information distinguishes the 'executive functioning working memory' from the working memory model as a whole and from other definitions in which working memory may be used to refer to the passive storage systems alone (Perry et al., 2001). The Cognitive Busyness model of Lieberman (2000) references executive functioning working memory as the cognitive process on which anxiety has its proposed adverse effect on information processing. Utilizing findings from the areas of working memory, personality, and neurophysiology Lieberman (2000) proposed that cognitive busyness would be positively correlated with the personality trait of introversion. He based this on the hypothesized increase in cortical arousal from heightened activity of the ARAS in introverts (Eysenck, 1967). Based on known relationships between reticular brain stem projections to anterior frontal regions and dopamine modulation in the prefrontal cortex (Lieberman, 2000) and on the relationship between dorsolateral prefrontal involvement in working memory functioning (Cabeza & Nyberg, 1997), Lieberman specifically proposed that extraverts should outperform introverts on measures of central executive working memory functioning. Because sociability is a sub-factor of the extraversion dimension (H. Eysenck, 1992) and decreases with decreasing levels of extraversion, social anxiety (like higher levels of introversion) would be thought to be related to decremented cognitive task performance in a similar fashion via increased levels of cognitive interference (Zarantonello et al., 1984).

To evaluate his hypothesis, Lieberman (2000) administered the Eysenck Personality Inventory to twenty-eight college volunteers. Participants were divided into the most introverted (mean EPI = 9.98) and extraverted (mean EPI = 15.78) subjects representing the extreme quartile scores. They were administered the Sternberg memory-scanning task, a test of executive working memory functioning. Because the task involves not only the passive storage of the previously presented stimuli but also active manipulation via the comparison task of the probe digit with the passively-stored number string, the Sternberg memory scanning paradigm is thought to directly tap the central executive component of working memory.

As expected, Lieberman (2000) found that extraverts exhibited faster reaction times on the Sternberg task. These results provide tentative support for the hypothesized relationship between the personality domain of introversion/extraversion and efficiency in executive functioning working memory. Lieberman (2000) posited that this relationship reflected innate, biologically-mediated cognitive processing differences between introverts and extraverts. Because of the proposed biological substrates and temporal stability of this phenomenon, Lieberman characterized it as reflecting 'trait cognitive busyness'.

Although the finding of Lieberman relating the trait personality factors introversion and extraversion with working memory is compelling, Lieberman did not report state measures of anxiety. This factor may have contributed importantly to the obtained results within the trait-based cognitive busyness model. The relationship between cognition and personality has often been framed as a 'state' function with increased anxiety/arousal at the time of the assessment being associated with decreased cognitive performance. Thus the impact of anxiety in the context of Lieberman's paradigm needs to be examined. If state anxiety is itself adversely impacting cognitive performance then Lieberman's trait-based cognitive busyness model (2000) is an insufficient heuristic. However, if state anxiety is not adversely impacting cognitive performance (above and beyond the contribution of trait anxiety) then Lieberman's model would be a useful model in the anxiety and cognitive performance paradigms. One widely known model that incorporates the impact of state anxiety on cognitive processing is the Processing Efficiency Theory.

1.4.2 Understanding the relationship between anxiety and performance: The processing efficiency theory

M. Eysenck and Calvo's Processing Efficiency theory (M. Eysenck & Calvo, 1992) proposes that the anxiety that is aroused during the process of taking a test ('test anxiety') provides a common example of the interaction of an acute anxiety condition and cognitive task performance. As with trait anxiety conceptualizations, M. Eysenck and Calvo emphasize that situational test anxiety involves two basic components that involve cognitive worry (preoccupation with evaluation) and affective arousal (tonic level of physiological reactivity). Based on the Processing Efficiency theory, higher anxiety is predicted to be disrupting to task performance having multiple demands due to increased cognitive worry during the task. Worry's impact on performance has been conceptualized as creating an interference effect on limited capacity attentional resources (Wine, 1982). Two primary hypotheses have been logically derived from the processing efficiency model: 1) Those high in text anxiety will generally underperform those individuals low on test anxiety on a given task, and 2) As the task difficulty increases, a progressively larger discrepancy between low and high test anxiety subjects should be demonstrated (M. Eysenck & Calvo, 1992).

However, these hypotheses are in contrast to existing theoretical heuristics. For example, it is known that worry and arousal components of anxiety impact task performance in more complex ways then the processing efficiency theory would suggest. The most obvious example of a theoretical heuristic that contrasts with the Processing Efficiency theory is the Yerkes-Dodson law (1908). In short, the Yerkes-Dodson law states that the improvement or decrement in performance is in response to the total level of situational arousal. As a result, too much or too little arousal is detrimental for task performance and a 'middle ground' of arousal exists that is most optimal for performance. The Yerkes-Dodson (1908) effect utilizes the factor of individual differences in baseline arousal dictating where the optimal range of arousal sits for any given individual-situational (state) interaction. This model contrasts with the Processing Efficiency theory's emphasis on a linear relation between state arousal and performance disruption. Based on this contrast, the Processing Efficiency theory is at best a descriptive explanation of some aspects of the effects of situational anxiety on cognitive performance.

The above findings establish that individuals who endorse either acute (state) or longstanding symptoms of anxiety (trait anxiety) evidence significantly greater cognitive processing disruption in complex cognitive tasks as compared to those who do not report subjective anxiety. The previous presented findings on introversion suggest that social anxiety may represent a specific feature of trait anxiety relating to the executive functioning difficulties characterized as cognitive busyness in introverts (Lieberman, 2000). This also suggests that social anxiety, as a longstanding trait, is associated with distinct neurobiological mechanisms represented by both heightened baseline arousal levels as well as executive functioning difficulties. Given this, it might be suspected that specific executive functioning difficulties might be evidenced in individuals who have clinically-significant levels of social anxiety.

Recent data in support of the proposed relationship between executive functioning difficulties and social anxiety have been provided by a study conducted by Cohen and colleagues (Cohen et al., 1996). Neuropsychological performance features of psychiatric normal controls were compared with individuals with obsessive-compulsive disorder (OCD) or social phobia (SP). The Trail Making Test (TMT, Reitan, 1958) Part A was used as a measure of simple visuomotor tracking and Part B was used as a measure of complex executive functioning measure. Cohen et al. (1996) expected that the OCD group would demonstrate lower scores on a measure of executive functioning in comparison with the other groups.

The study results showed that the social phobia anxiety disorder group was significantly slower than both the normal control and OCD groups on TMT Part B. However the social phobic's were only slower than the control group on the simple TMT Part A task. Because of the potential confound of situational state anxiety on cognitive task performance, the researchers also compared the effects of situational anxiety on cognitive test scores for both the social phobia and OCD clinical groups. There were no significant correlations between state anxiety and the TMT A or B tasks for either group. Thus, situational state anxiety did not explain the disrupted performance of the social phobia group on either the simple visuomotor tracking task or the complex working memory executive task.

The findings of Cohen et al. are consistent with numerous other researchers (e.g., Zarantonello, Slaymaker, Johnson & Petzel, 1984; see Sarason, Pierce & Sarason, 1996) who have posited and demonstrated the cognitively interfering impact of trait-based anxiety on cognitive performance. These findings, considered in conjunction with Sarason et al.'s cognitive interference theory, the findings on Extraversion, and the related findings on behavioral inhibition, suggest that overaroused introversion and behavioral inhibition represent related, neurobiologically-based temperamental characteristics that are predictive of later social anxiety and that may be expected to co-occur with cognitive weaknesses on complex executive functioning working memory tasks. In addition, the lack of a relationship between measures of situational anxiety and performance on the executive working memory task (Cohen et al., 1996) lends further support to the expectation that cognitive processing differences on complex executive functioning measures would be associated with longstanding, stable, neurophysiologically-based individual differences in social anxiety.

1.4.3 Summary: Cognitive interference, anxiety, and introversion/extraversion

The data presented from Lieberman (2000) and M. Eysenck and Calvo (1992) outline the relationship between cognitive interference and 1) increased levels of introversion and 2) increased levels of anxiety. Additionally, the Cohen et al. study (1996) demonstrated executive functioning weaknesses in a clinically-diagnosed social anxiety sample that did not vary based on state anxiety levels. If social anxiety is per se the specific feature of introversion that results in executive functioning weaknesses, then cognitive processing weaknesses on executive functioning tasks may be expected to be evidenced in non-clinical samples with high levels of social discomfort. In addition, social discomfort would also be expected to be associated with differences in other aspects of cognitive processing that have been demonstrated in relation to extraversion.

1.5 Automatic and controlled processing and introversion/extraversion

In addition to the findings related to central executive working memory functions, another cognitive processing arena where differences have been examined in relation to the extraversion personality dimension involves the area of automatic and controlled information processing (Ackerman, 1986). Schneider and Shiffren's (1977) information processing theory introduced an explicit distinction between cognitive or performance tasks in which the temporal transition of cognitive performance skill level from novel to well-practiced was relatively easy and those cognitive tasks in which this transition was relatively difficult (or impossible due to time constraints). These task characteristics were denoted as tapping "automatic" or "controlled" types of information processing, respectively (Ackerman, 1986).

According to the model, automatic processes are defined as being relatively fast, cognitively effortless (or nearly so), amenable to implicit learning, and fairly unamenable to an individual's conscious control. Automatic processes generally develop as a result of sustained practice and directed effort during initial learning that ultimately becomes automated into learned routines, such as playing a piano, driving a car, and swimming. In contrast, controlled processes are defined as those tasks without consistent rules and/or consistent sequences of information processing components in which information must be consciously processed (e.g. active problems solving such as in the Wisconsin Card Sort Test). Additionally, controlled processing is indicated when tasks are novel or when the subject may not internalize consistencies that would be appropriate for automatic processing of the task situation. According to Ackerman (1986), when a task procedure lends itself to automatic processing the information processing that the subject is performing is called "consistent mapping", based on the repetitious, automatic nature of the task performance. In comparison, when a subject is performing controlled processing they are said to be engaged in "variable mapping", which requires active conscious processing for successful completion.

While the extent to which the Extraversion dimension impacts on the learning of automatic and controlled processes has yet to be directly evaluated, one study (Corr, Pickering & Gray, 1995), measuring the differences in procedural/implicit memory functioning between introverts and extraverts, found that introverts demonstrated significantly better performance than extroverts on a procedural memory task. The task required the subjects to identify, as quickly as possible, in which of four quadrants a target would appear. Unknown to the subjects, on 40% of the trials a rule determined in which quadrant the target would appear. Consistent with the researchers' hypothesis, the introverted group outperformed the extraverted group, automatically incorporating the implicit rule into their decision-making. In that implicit learning/memory tasks are specific examples of the more general category of automatic processing tasks, a logical hypothesis one could draw from this study is that introverts would be expected to learn automatic processes (those requiring consistent mapping) better than extraverts.

Consistent with the prediction that introverts should outperform extroverts on implicit memory tasks, Lieberman's (2000) study demonstrated that extraverts outperformed introverts on an executive function working memory task. Such a task requires the use of more active, explicit information processing resources. Given that extroverts were found to be less susceptible to the effects of cognitive busyness on cognitive functioning (Lieberman, 2000), extraverts also should have relatively less difficulty performing on tasks that require actively inhibiting cognitively interfering information. These tasks can be characterized as a controlled cognitive processing operation.

The effects of cognitive busyness have when contrasting a simple 'consistent mapping' automated task and a more complex 'variable mapping' controlled-processing task are unknown. It is possible that the advantage introverts seem to have on simple, procedural memory tasks (Corr, Pickering & Gray, 1995) may be negated by excessive levels of cognitive busyness. In order to evaluate features of automatic and controlled processes in relation to stable, temperamental individual differences, it would be useful to examine tasks that contrast the passive automatic store components and the active central executive processing features of Baddeley's working memory model (1986; see figure 1). Automatic processes would be expected to disproportionately engage the passive storage component of working memory. In contrast, controlled-processing tasks would be expected to activate the more active, dynamic parts of working memory. The contrast (if any) between performance in these areas can be seen as a proxy measure of executive dysfunction.

In order to evaluate cognitive interference and the relevant working memory processes related to the cognitive busyness construct (along with automatic and controlled processes), it is necessary to evaluate the cognitive measures that have been developed for evaluating these processing constructs. The specific measures of interest are those that have been related to contrasting automated processing with controlled inhibition of automated processes and of contrasting simple working memory with central executive working memory functions. By looking at all of these distinctions, the relationship between social discomfort and cognitive processing can be deconstructed and better understood.

1.6 Tests of executive functioning and central executive working memory processes

There are many facets of executive functioning and the central executive component of working memory, including selective attention, response inhibition, strategy selection, online storage of auditory or visuospatial information, manipulation and retrieval of information, and simultaneous processing of information presented via single or multiple modalities (e.g., auditory and visual modalities; Perry et al., 2001).

The combination of selective attention and inhibition is critical for guiding our ability to process task-relevant stimuli and to ignore task-irrelevant stimuli (Leung, Skudlarski, Gatenby, Peterson & Gore, 2000). Competing information-processing demands, synonymous with the creation of cognitive interference, require the capacity to selectively attend to target material and inhibit interfering information. The relevance is obvious: if one cannot modulate their attention through controlled, executive inhibition processes, they are vulnerable to the experience of attempting to perceive and process multiple concurrent streams of stimuli. This can directly lead to decrements in cognitive performance via one (or both) of two mechanisms. The first derives from the condition of cognitive overload and saturated working memory capacity, while the other is a consequence of the anxiety created by the subjective sense of being 'overwhelmed' by a demanding task (Leung et al., 2000).

One test used to measure selective attention and response inhibition is the Stroop Interference Test (1935). While different versions of the Stroop exist, in all versions at least two separate parts are administered. One part consists of words that are read out loud in the way that they are written (e.g., "red", "tan"), and the second part consists of naming the color of words that have been printed incongruent to the word meaning (e.g., the color of the printed word contrasts with the meaning of the printed word itself). The primary findings are that performance is faster on the automated word-reading component of the test in comparison with the controlled processing condition in which the printed word meaning must be inhibited in order to state the incongruent printed word color

(Stroop, 1935). Thus, the Stroop test represents a classic comparison of automated and executive effortful controlled processes.

Besides selective attention/response inhibition, another important component of executive functioning is simultaneous information processing and the ability to rapidly alternate cognitive sets. The Trail-Making Test (TMT) (Reitan, 1958) is a paper and pencil task with two parts (Parts A and B) that respectively represent simple attention and alternate set shifting, the latter of which requires active executive function processing for completion. The TMT Part A requires the subject to connect twenty-five sequential numbers placed in a random visual array on a single sheet of paper (drawing a line between them in sequential order, from 1" to "2" to "3", and so on), in a simple attention tracking task. In contrast, Part B consists of numbers and letters placed in a random visual array on a single sheet of paper that must be rapidly connected in alternating sequential order (drawing a line from "1" to "A" to "2" to "B" and so on). Because of the increased processing complexity, Part B requires longer to complete than Part A (Lezak, 1995). However, in addition to its increased complexity and central executive functioning requirements, TMT B also is longer (by fifty-six centimeters; Gaudino, Geisler & Squires, 1995).

Within the working memory tradition, the testing of the phonological loop is considered essential as it represents a critical part of the evaluation of sustained attention and online storage/manipulation/retrieval. As part of the Wechsler Adult Intelligence Scale-III (WAIS-III), the Digit Span task (Wechsler, 1997) is thought to be a core test of working memory associated with its two parts, span forward and span backward. In Digit Span forward, the subject is required to repeat back a series of digits presented auditorally, requiring activation of the passive phonological working memory store. Based on this characterization, it is generally accepted that Digit Span forward is a measure of sustained attention associated with the passive phonological working memory store (Perry et al., 2001). In Digit Span backward, the subject is required to repeat back the numbers presented but in the reverse order, which requires not only the passive phonological working memory store but also the active manipulation capacity of the central executive working memory component. Because of its engagement of the central executive portion of working memory, Digit Span backward is considered a task that directly taxes executive functioning working memory (Gold, Carpenter, Randolph, Goldberg & Weinberger, 1997).

Based on all of the preceding data we can posit with confidence that there exists common underlying neurophysiological substrates and that these substrates impact specific personality/temperament (e.g., social anxiety) constructs and particular types of cognitive processing in predictable fashions. While theoretically compelling this relationship has rarely been directly tested, probably in part due to the practical difficulties of neuroimaging research (e.g., monetary expense). For that reason, proxy measures of both anxiety and cognitive operations are commonly used to infer more specific neurophysiological activity and can be thought to be an ecologically valid methodology to examine these phenomena.

1.7 Present study

The goal of the present study was to evaluate simple automated attention, controlled executive functioning and working memory processes in a nonclinical sample of adults who vary in degree of self-reported social discomfort. Simple attention and automated processing skills were evaluated with the Stroop Neuropsychological Screening Test (SNST; Stroop) Color task ('read the printed word regardless of its printed color') and the Trail Making Test (TMT) Part A. Controlled executive functioning processes were evaluated with the Stroop Color-Word task ('state the printed color of the word while inhibiting the printed word meaning') and the TMT Part B task (rapid set shifting). The Digit Span (DSp) forward span task was administered to evaluate the passive storage component of a working memory and the central executive working memory component was evaluated with the DSp backward span task. Self-reported social discomfort was evaluated with the Social Interaction Anxiety Scale (SIAS; Heimberg, Mueller, Holt & Hope, 1992).

The main hypothesis of the present study was that those subjects having higher levels of social discomfort would underperform those having lower social discomfort on the complex executive functioning tasks. Demographics (i.e., ethnicity and education), general intellectual functioning level, and simple task performance were controlled for. Because the study involved three measures of more basic and complex executive functioning processes, three subhypotheses are derived. These subhypotheses are as follows:

H1: Higher social discomfort scores would predict a significantly longer time to complete the Stroop Color-Word task. It was postulated that the completion time on the Stroop Color-Word task represented a proxy measure of cognitive interference/busyness via the conduit of controlled response inhibition. The complex nature of the task activates the executive functioning portion of working memory. Therefore, it was proposed that social discomfort scores would predict time to complete the interference portion (i.e. Color-Word) of the Stroop task.

H2: Higher social discomfort scores would predict a significantly longer time to complete Part B of the Trail Making Test. It was expected that the relative complexity (i.e., the activation of the central executive component of working memory) of Part B would create and/or tap increased cognitive busyness, and that this would relate to decremented task performance (i.e. increasing Part B raw time).

H3: Higher social discomfort scores would predict significantly less digits correct on the backward portion of the digit span task. In addition to its characterization as a measure of simple and complex working memory functions, Digit Span also is very susceptible to the impact of state anxiety (Lezak, 1995). The backward task directly engages the central executive portion of working memory, making it suitable for the present study.

2. Methods

2.1 Participants

The participants included in the present project were administered the self-report SIAS questionnaire and the cognitive performance tasks as part of an existing study (protocol G183LZ) researching the impact of Pyridostigmine, Deet and Permethrin on physical and cognitive performance under stress. Institutional Review Board approval was obtained for data collection in the larger study and for analysis of data in the present project (protocol T072FP). The data examined were obtained from twenty-nine subjects who completed the evaluation before the analyses for the present project were conducted (23 men, 6 women). Exclusion criteria in the larger study included medical diagnosis with diabetes, chronic fatigue syndrome, or fibromyalgia, any history of clinical depression, thyroid and other endocrine diseases, bulimia or anorexia, hypertension, cardiac disease, liver disease, obesity, and use of chronic medications or nutritional supplements. All identification data were coded so that there was no connection between the subject's actual identification and the study identification code available in the data. Descriptive information of the current study sample is provided in Table 1.

Insert Table 1 about here

2.2 Measures

The Social Interaction Anxiety Scale (SIAS; Heimberg, Meuller, Holt & Hope, 1992) self-report measure was used to assess the degree of social discomfort of the participants. This measure evaluates an individual's relative comfort level when interacting with others vice when they are alone (see Appendix A). Three cognitive performance tests were used. All three tests contained both a simple attention/working memory task and a complex executive functioning working memory task. The specific tests used were the Stroop Neuropsychological Screening Test (Trenerry, Crosson, DeBoe and Leber, 1989), the Trail Making Test (Reitan, 1958) and the Digit Span test

(Wechsler, 1997). The overall scores for all participants on these six measures are presented in Table 2.

Insert Table 2 about here

2.2.1 Social Interaction Anxiety Scale (SIAS; Heimberg et al., 1992)

The SIAS is a 20 item, self-report scale designed to measure anxiety in contingent situations where the individual must interact with others. It uses a likert scale with the anchors 0 (not very characteristic or false) and 4 (extremely characteristic or true). The SIAS has been found to have good internal consistency (alpha = .85-.93) and good test-retest reliability (r = .86). The measure is not a social phobia clinical measure per se and thus normative data is not used in the present (clinically normal) sample.

2.2.2 Stroop Neuropsychological Screening Test (SNST; Trenerry, Crosson, DeBoe & Leber, 1989)

The Stroop Neuropsychological Screening Test (SNST; Stroop) is a test of executive functioning efficiency (MacLeod, 1991). It was standardized on 156 adults ages 18-79 years. It has demonstrated excellent test-retest reliability, (r = .90). The SNST taps the ability of the individual to inhibit their normal response in an overlearned activity (i.e. reading) and adapt to a novel task (i.e. naming the color). The overlearned activity, reading, is considered an overlearned, automated simple attention task. The novel activity, color naming, is thought to engage complex executive functioning working memory via the requirement to actively inhibit the prepotent response of reading. In this study the data of interest are the times to completion for both the simple (i.e. color) and the complex (i.e. color-word) tasks.

2.2.3 Trail Making Test (TMT; Reitan, 1958)

The Trail Making Test (A and B) is a paper and pencil psychomotor tracking task (Reitan, 1958). Interrater reliability has been reported at .94 for Part A and .90 for Part B. Test-retest (12-week) reliability has been found to be .46 for Part A and .44 for Part B. Reflecting the differing demands on cognitive domains, Parts A and B correlate only .49 with each other. The first portion, Part A, is a simple psychomotor tracking task that taps basic attentional functioning. The second part, Part B, is a more complex task involving not only psychomotor tracking but also executive functioning via the requirement to shift cognitive set (thereby engaging executive functioning working memory). The data of interest is the raw time to completion for Parts A and B.

2.2.4 Digit Span (DSp; Wechsler, 1997)

The Digit Span task is part of the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) (Wechsler, 1997). The Digit Span task has demonstrated good psychometrics, with a split-half reliability of .90 and a test-retest reliability of .83. It consists of two parts, Digit Span forward and Digit Span backward. The forward portion requires the engagement of transient storage in the phonological loop component of working memory by requiring the subject to repeat a recited number string. The backward portion requires the engagement of executive functioning working memory by requiring the subject to repeat the recited numbers in reverse. The data of interest are the maximum number of digits correct in both the forward and backward conditions.

2.2.5 Shipley institute of living scale (Zachary, 1996)

The Shipley Institute of Living Scale is a test of general intellectual functioning (Zachary, 1996). It consists of two subtests, a 40-item vocabulary test and a 20-item test of abstract thinking. The verbal section taps basic word knowledge while the abstraction section taps complex, logic-based problem solving. The Shipley shows good psychometric properties (split-half reliability ($r = 0.92$), test-retest reliability ($r = 0.80$)) and correlates well with more comprehensive tests of intellectual functioning, including the Wechsler Adult Intelligence Scale-Revised (WAIS-R) ($r = 0.74$). In this study the data of interest are the combined sub-test age and education adjusted T-score.

2.3 Data analyses

The study hypotheses were tested using multivariate regression analysis. In order to evaluate the contribution of demographic and general intellectual ability on the cognitive processing dependent variables, bivariate correlational analyses were conducted. Based on these relationships and the known relationship between ethnicity, education, general intellectual functioning, and simple task performance on similar complex task performance, these variables were entered in a hierarchical linear regression model. In the last block the predictor of interest, the SIAS, was entered.

The complex executive functioning task (i.e. Stroop, Color-Word, TMT Part B, and Digit Span backward) was used as the dependant variable. The order of entry and organization of the variables controlled for were as follows:

Block 1: Ethnicity (Caucasian or other), education (total number of years of formal education)

Block 2: Shipley total score (general intellectual functioning)

Block 3: Simple task performance (either Stroop Color, TMT Part A, or Digit Span forward)

Block 4: SIAS score

The dependent variables for the Stroop and TMT tasks were the times to completion while the maximum number correct was the dependent variable for each of the Digit Span tasks. Because of the relatively small number of non-Caucasians, they were combined for purposes of data analysis. An alpha level of .05 was used for determining significance in all comparisons. All statistical analyses were completed with the Statistical Package for the Social Sciences software (SPSS for Windows, release 10.0.5).

3. Results

Because of the use of time as a measure in two of the three dependant variables, a Kolomorov-Schmirnov test for normality of distribution was conducted. No significant deviations from normality were found, hence all time data remained untransformed.

3.1 Correlational analyses

Bivariate correlation analyses were first conducted, in order to examine the relationships between the dependent variables, the SIAS social discomfort measure, and select demographic variables (see Table 3). As expected, significant correlations were found between the SIAS and the Stroop Color-Word task and TMT Part B. In contrast, no significant correlation was found between the SIAS and either the forward or backward Digit Span tasks. Additionally, bivariate correlations between the dependant variables (and the related simple tasks) with the number of years of formal education completed and with estimated intellectual ability on the Shipley Institute of Living Scale (Zachary, 1996) were conducted, based on the well-established contributions of education and intellectual ability to cognitive processing (Lezak, 1995). Of the twelve possible permutations, only two were non-significant (the Shipley correlations with the Color and Color-Word tasks of the Stroop; see Table 3).

Insert Table 3 about here

3.2 Hypothesis 1 - Stroop task

The hypothesis involving the Stroop task posited that higher social discomfort would significantly predict longer time to complete the Stroop Color-Word task when demographics, general intellectual functioning level and simple task performance were accounted for. The results are presented in Table 4.

Insert Table 4 about here

The results of the four-block hierarchical regression indicated that the model was significant ($R^2 = 0.45$, F (5,23), $p < .001$). The SIAS predicted a significant amount of the variance in the Stroop Color-Word performance with the other control variables were accounted for (R^2 change = 0.14, F (5,23), $p < .02$).

3.3 Hypothesis 2 - Trail Making Test

The hypothesis involving the TMT task higher social discomfort would significantly predict longer time to complete the TMT Part B task when demographics, general intellectual functioning level and simple task performance were accounted for. The results are presented in Table 5.

Insert Table 5 about here

The results of the four-block hierarchical regression indicated that the model was significant, ($R^2 = 0.68$, F (5,23), $p < .001$). The SIAS predicted a significant amount of the variance in TMT Part B performance with the other control variables were accounted for, (R^2 change = 0.18, F (5,23), $p < .001$).

3.4 Hypothesis 3- Digit Span task

The hypothesis involving the Digit Span task predicted that higher social discomfort would significantly predict less digits completed on the Digit Span backward task when demographics, general intellectual functioning level and simple task performance were accounted for. The results are presented in Table 6.

Insert Table 6 about here

The results of the four-block hierarchical regression indicated that the model was significant, ($R^2 = 0.51$, F (5,23), $p < .001$. The SIAS did not predict a significant amount of the variance in Digit Span backward performance above and beyond the control variables, ($R^2 = 0.01$, F (5,23), $p > .10$.

3.5 Analysis of social discomfort between-group differences in executive functioning

A series of GLM univariate analyses of covariance (ANCOVAs) were conducted to evaluate between-group differences on each of the study dependent variables, covarying the number of years of education completed, estimated intellectual ability, and simple task performance. Groups were created using the guidance of Kagan (1989) regarding the distribution of behavioral inhibition in the general population (operationalized as the highest 20% of SIAS scores). The primary hypotheses were that the high social discomfort group would underperform the normal group on the complex measures of executive functioning working memory. Consistent with the results of the multivariate regression analyses, the hypotheses were supported for the Stroop Color-Word and TMT Part B tasks but not the Digit Span backward task.

To test the possibility that these results were obtained because the high social discomfort group either was intellectually less capable, was impacted by general anxiety in the testing context of sufficient magnitude to impair general test performance, or was not as adept in general test-taking skills as the normal group, between-group differences on additional measures of cognitive performance that require abstract reasoning and active processing at the time of the testing also were evaluated on a posthoc basis. No significant differences between the groups was obtained on estimated intellectual ability ($p=.12$) from the Shipley Institute of Living Scale (Zachary, 1996) or on the WAIS-III (Wechsler, 1997) Similarities ($p=.23$) or Matrix Reasoning ($p=.75$) subtests that represent verbal and nonverbal abstract reasoning abilities, respectively.

3.6 Summary

The Stroop Color-Word task, TMT Part B and the backward portion of the Digit Span task were included in this study as measures of complex executive functioning. The findings on both the Stroop Color-Word task and Part B of the TMT demonstrated statistically significant independent contribution of the SIAS score when accounting for ethnicity, education, general intellectual functioning, and simple task performance. The simple tasks consisted of the Stroop Color task, the TMT Part A, and the forward portion of the Digit Span task. In contrast and contrary to predication, there was no independent contribution of the SIAS score on performance on the backward portion of the Digit Span task when the control variables were accounted for.

4. Discussion

Based on these results, a significant relationship was observed between reported social discomfort and performance on measures of complex executive functioning when controlling for potential confounding variables. These findings lend support to two of the three hypotheses.

There are several possible reasons that may explain the unexpected result regarding the Digit Span task. While all three of the primary tests have components that tap both the more basic, simple processing components as well as more complex executive functioning resources, the Stroop task, the Trail Making Test and Digit Span are inherently different tests that involve separate cognitive processing resources. The Stroop test combines a highly automated overlearned basic reading skill condition (Color task) with a strong response inhibition factor in the conflict (Color-Word task) condition. The TMT, being a paper and pencil task, has a strong psychomotor speed component that also taps basic visual attentional resources in the simple task (Part A) and executive set-shifting capacity in the complex part (Part B). Finally, the Digit Span task taps different components of the working memory system, involving the passive auditory phonological loop (DSp forward) and the central executive manipulation component (DSp backwards).

The most unexpected finding in this study involved the Digit Span task. Given the known differences between the processing resources tapped by the forward and backward span tasks (for a review see Perry et al., 2001), this seems to be an important finding to understand. While speculative, one hypothesis is that the participants who had greater difficulties with social discomfort also would have greater difficulties with sustained attention/concentration aspects of the passive phonological storage component of working memory. The Digit Span task is thought to have a bifurcated performance process, with step one involving sustained attention and encoding and step two involving accurate recall, manipulative sequencing and vocalization of the information (Bannatyne, 1974). Obviously, if subjects have a problem in step one, any differences involving step two (e.g. the manipulating of the digits) would be masked.

Although theoretically compelling, this explanation leaves open the question of why this finding did not manifest on the other two tasks. One possibility, alluded to above, is that the Stroop task and the TMT have a less bifurcated performance model (or that the bifurcation does not involve simple attentional resources to the same degree as in the Digit Span task) and thus the distinctions between the simple and complex tasks are more clearly delineated. This is supported by the observation that while the Stroop task and the TMT involve physical stimuli in front of the participant, the Digit Span task is exclusively verbal. This may increase concentration demands and excessively penalize those who are more distractible. Another possible explanation for the Digit Span finding is that it is not timed, while the Stroop task and the TMT are timed. This may serve to focus the participant on the task at hand and may, especially in high-functioning participants (i.e. those used to timed testing situations), reduce off-task thoughts that would impair performance.

One final explanation for the Digit Span finding may involve the key role of working memory in the Digit Span task as a whole. The Digit Span forward task relies on the passive phonological loop component of working memory while Digit Span backwards consists of engagement of the phonological loop plus engagement of the central executive portions of working memory. Thus, both components of the digit span task have substantial working memory demands. In contrast, the TMT Part A is a simple visual attention task with few working memory requirements, and the Stroop Color task is a highly automated, overlearned reading task that also requires little or no working memory resources as primary demand features of the task. Moreover, as can be seen in Table 3, the Digit Span tasks correlate with each other more then either the Stroop tasks or TMT tasks correlate with each other. Thus, social discomfort may be related to neurobiological mechanisms of the working memory system in its entirety (or with the phonological loop component of working memory) rather than of the central executive component alone.

In Lieberman's cognitive busyness study (2000), introverts were found to underperform extraverts on a working memory measure. As it is established that high social anxiety is one of the behavioral manifestations of high introversion, we believe that our social discomfort measure represents the core feature of introversion associated with its presumed neurobiological underpinnings. The findings from this study partially support the findings of Lieberman. Those with higher social anxiety, who are presumed to be prone to higher levels of cognitive busyness, were found to underperform those with lower social anxiety presumed to have lower levels of cognitive busyness. Similarly, these results extend the findings of Cohen et al., (1996), who found that a social phobia group underperformed a normal control and OCD group on the TMT Part B. Although our subject pool was high functioning and non-clinical, those with higher self-reported social anxiety manifested relative deficits on tests of executive functioning working memory.

4.1 Study limitations

Several limitations of this study are noteworthy. The subjects were a very homogeneous group and this factor almost certainly introduced a restriction of range issue. The subjects were healthy normals, mostly male and Caucasian, and highly educated (see Table 1). The extensive testing experience and high level of education of most of the subjects may have attenuated or otherwise impacted our findings. Additionally, this factor limits the generalizability of the findings to the population as a whole.

As shown in Table 3, the measures used as the dependant variables for executive functioning correlated not only with social anxiety but also with each other. The dependent measures (Stroop Color Word, Trail Making Test B, and Digit Span backward) were chosen to assess a common neuropsychological construct, possibly reflecting an underlying neurophysiological substrate with specific cognitive and behavioral manifestations. It is therefore possible that the results of the dependent measures are not independent and future studies need to adjust for multiple comparisons. The study would have benefited from additional, comprehensive measures that could have addressed some of these factors (e.g., a comprehensive personality measure). This would also have improved the ecological validity of the study given that much of the background literature is based on personality constructs.

Another limitation with this study was the lack of a specific state anxiety measure. Given this omission, it may be argued that increased state anxiety would itself account for our findings and that by focusing on high social anxiety we actually 'cherry-picked' those who would be impacted most adversely during cognitive testing. While intuitively appealing, given the totality of our findings as well as the current state of knowledge in the relevant research areas, this explanation is insufficient. The subjects were tested with a large number of cognitive metrics designed to capture the subject's general level of functioning across a large variety of different cognitive domains. If, for example, the phenomena at work were situational anxiety and/or test anxiety, it would be expected to create a generalized decrementing of test results. This was not our finding; in fact, based on a partial analysis of some other tests co-administered at the time of the testing in this study, the complex executive functioning tasks stand out from the other testing results in their statistically significant results.

Another reason that state anxiety alone cannot be postulated to explain all of our results involves the research in the temperament arena. As state anxiety is known to be highly correlated with trait anxiety (M. Eysenck & Calvo, 1992), and trait anxiety is highly correlated with behavioral inhibition (Kagan et al., 1987), the most relevant issue is not one of cross-sectional anxiety but rather of temporal sequence. Given this assumption, the research on temperament becomes paramount.

As the earlier data on the longitudinal relationship between behavioral inhibition and anxiety demonstrated (Kagan et al., 1987; Schwartz et al., 1999) there is good reason to believe that one begins life with a certain neurophysiological makeup that stays fairly consistent over time. As the findings of Lieberman (2000) demonstrates, that stable neurophysiological makeup can impact cognitive functioning (specifically in the executive functioning working memory arena). In short, to state that higher state anxiety may adversely impact certain realms of cognitive functioning is descriptively correct but explanatorily insufficient. Additionally, as the results of Cohen et al. made clear (1996), differences in state anxiety cannot always account for differences in neuropsychological test findings in groups with varying clinically diagnosed anxiety disorders. Given these facts and our data, we propose that state anxiety alone cannot account for the statistically significant impact of social discomfort on two measures of complex executive functioning.

4.2 Future directions

With the extensive empirical research findings on the relationship between physiological factors and social anxiety (as presented in the background section of this study), and the newer findings involving social engagement (i.e. social phobia, introversion) (Cohen et al., 1996; Lieberman, 2000) and executive functioning, it seems reasonable to conclude that cognitive, characterological and physiological factors should be evaluated in relation to one another. A growing movement within both clinical and research psychology recognizes the interaction of the cognitive and physiological determinants of behavior. This is known as the 'Cognitive Neuroscience' movement (CN; Gazzaniga, Ivry & Mangun, 1998).

It is proposed that the CN model of research, integrating neural substrates, behavior, and cognitive processing, should serve as a heuristic for investigation into the phenomena of co-existing behavioral inhibition/social anxiety and cognitive interference.

This could be accomplished in several ways. One would be to further utilize the tools of neuroscience (e.g. neuroimaging) to determine the neural correlates of personality constructs, social anxiety and cognitive performance on a variety of tasks. Another would be to use neuroimaging studies in a longitudinal fashion. By integrating results from cognitive assessments, these developmental data could shed light on the progression of both social anxiety and cognitive interference. A less direct method but nonetheless appropriate use of a CN model would be to use proxy measures of both social anxiety (and, more generally, personality) (e.g. questionnaires) and information processing (e.g. cognitive testing results) and evaluating their combined, interactive relationship with cognitive interference task performance (e.g. using a dual-task paradigm).

While the biological models of personality may lend themselves most directly to the CN heuristic, broader models of personality may be more appropriate. The use of a comprehensive model of personality, such as the Five-Factor model (FFM) (McCrae & Costa, 1987), may provide more information as to the specific personality correlates of cognitive interference and potentially shed more light of the topic then would be possible in any of the available biological models. For example, in H. Eysenck's model of personality social anxiety associated with cognitive interference may be associated with decreased levels of extraversion, increased levels of neuroticism, or some combination of the two. Using the FFM, the contributions of Openness, Agreeableness and Conscientiousness (domains not addressed in biological models) to social anxiety could be empirically derived and evaluated. Another personality inventory, the OMNI (Loranger, 2001), is similar to other FFM personality inventories but adds the personality dimensions of narcissism and sensation-seeking.

Future research in the information processing realm may benefit by utilizing a wider battery of traditional executive functioning measures as well as relatively new computer-based information processing measures, such as the S-CAT (Spaceflight Cognitive Assessment Tool). The S-CAT is part of the broader computerized battery known as the ANAM (Automated Neuropsychological Assessment Metrics; Kane & Kay, 1992). The S-CAT contains four of the seven tests in the ANAM; additionally, one test (Code Substitution) has a recall component to it, bringing to total number of tasks in the S-CAT to five. It is quickly administered (administration time is approximately fifteen minutes) and tests a number of relevant cognitive domains (including working memory/executive functioning, attention and memory). Additionally, the S-CAT offers an important advantage over traditional neuropsychological measures in that it is designed to be delivered over repeated administrations without introducing learning effects (Kane & Kay, 1992). By combining both traditional and non-traditional neuropsychological tasks with social anxiety and general personality measures, a more comprehensive understanding of the relationship between the two may emerge.

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APPENDIX A

SIAS

Rate items 1-20 using the following scale:

0 = not characteristic of me
1 = minimally characteristic of me
2 = occasionally characteristic of me
3 = often characteristic of me
4 = extremely characteristic or true of me

1. I get nervous if I have to speak with someone in authority (teacher, boss).
2. I have difficulty making eye-contact with others.
3. I become tense if I have to talk about myself or my feelings.
4. I find difficulty mixing comfortably with the people I work with.
5. I find it easy to make friends of my own age.
6. I tense-up if I meet an acquaintance in the street.
7. When mixing socially I am uncomfortable.
8. I feel tense if I am alone with just one other person.
9. I am at ease meeting people at parties, etc.
10. I have difficulty talking with other people.
11. I find it easy to think of things I can talk about.
12. I worry about expressing myself in case I appear awkward.
13. I find it difficult to disagree with another's point of view.
14. I have difficulty talking to attractive persons of the opposite sex.
15. I find myself worrying that I won't know what to say in social situations.
16. I am nervous mixing with people I don't know well.
17. I feel I'll say something embarrassing when talking.
18. When mixing in a group I find myself worrying I will be ignored.
19. I am tense mixing in a group.
20. I am unsure whether to greet someone I know only slightly.

APPENDIX B

Table 1

Subject Demographics

Variable	yrs/%	Total (n = 29)
Age (yrs)		
Mean	27.21	
SD	3.98	
Gender (%)		
Male	79.30	23
Female	20.70	6
Ethnicity (%)		
Caucasian	65.50	19
African-American	20.70	6
Hispanic	3.40	1
Asian	10.40	3
Education (%)		
High School (=<12)	17.20	5
Part college (>12,<16)	17.20	5
College grad (=16)	7.00	2
Post-grad (>16)	58.60	17

Table 2

Distribution of Stroop Times, Trail Making Test Times and Digit Span maximum number correct, all participants

Test	SNSTC	SNSTCW	TMT A	TMT B	DSpF	DSpB
Mean	49.38	103.31	16.66	39.21	7.48	5.76
SD	9.99	20.43	3.89	10.83	1.40	1.62
Minimum	34.00	64.00	11.00	23.00	5.00	3.00
Maximum	71.00	162.00	26.00	68.00	9.00	8.00

Note. SNSTC = Stroop Neuropsychological Screening Test color, SNSTCW = Stroop Neuropsychological Screening Test color word, TMT = Trail Making Test, DSpF = Digit Span Forward, DSpB = Digit Span Backward.

Table 3

Correlations and intercorrelations of simple attention/executive functioning measures (Stroop Neuropsychological Screening Test, Color and Color Word times, Trail Making Test Part A and B times, and Digit Span, forward and backward maximum number correct) with the social discomfort measure, Education level and Shipley Score

Variable	1	2	3	4	5	6	7	8	9
1. SIAS	---								
2. Education	-.24	---							
3. Shipley Scale	-.17	.67***	---						
4. SNSTC	.30	-.57***	-.34	---					
5. SNSTCW	.54**	-.41*	-.27	.62***	---				
6. TMT A	.24	-.47**	-.39*	.35	.52**	---			
7. TMT B	.56**	-.69***	-.50**	.52**	.67***	.57***	---		
8. DSpF	-.35	.46*	.40*	-.39*	-.39*	-.35	-.44*	---	
9. DSpB	-.33	.50**	.57***	-.59***	-.39*	-.35	-.41*	.70***	---

Note. SIAS = Social Interaction and Anxiety scale, SNSTC = Stroop Neuropsychological Screening Test color, SNSTCW = Stroop Neuropsychological Screening Test color word, TMT = Trail Making Test, DSpF = Digit Span forward, DSpB = Digit Span backward.

$^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

Table 4

Four Block Hierarchical Linear Regression Model of Stroop Color-Word Performance

Model and Variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	B	SE B	β
(Block 1 – Control Variables)	.21*	.15*	.21*				
Ethnicity				-.10	-5.20	7.39	-.12
Education				-.03	-.38	1.81	-.05
(Block 2 – Intellectual Functioning)	.21	.12	.00				
Shipley Score				-.01	-.01	.78	-.01
(Block 3 – Simple Task)	.41**	.31**	.20**				
Stroop Color				.39	.98	.36	.48*
(Block 4 – Social Anxiety Predictor)	.55***	.45***	.14*				
SIAS score				.38	.65	.24	.48*

Note. sr^2 = semi-partial correlation, which describes the percent variance accounted for by each predictor

*$p < .05$. ** $p < .01$. *** $p < .001$.

Table 5

Four Block Hierarchical Linear Regression Model of TMT Part B Performance

Model and Variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	*B*	SE B	β
(Block 1 – Control Variables)	.47***	.43***	.47***				
Ethnicity				-.20	-5.44	3.01	-.24
Education				-.34	-2.19	.69	-.49**
(Block 2 – Intellectual Functioning)	.48***	.41***	.00				
Shipley Score				-.01	-.01	.32	-.01
(Block 3 – Simple Task)	.55***	.48***	.07				
TMT Part A				.20	.66	.35	.24
(Block 4 – Social Anxiety Predictor)	.73***	.68***	.18***				
SIAS score				.43	.39	.10	.54***

Note. sr^2 = semi-partial correlation, which describes the percent variance accounted for by each predictor

*$p < .05$. ** $p < .01$. *** $p < .001$.

Table 6

Four Block Hierarchical Linear Regression Model of Digit Span Backward Performance

Model and Variables	Unadjusted R^2	Adjusted R^2	R^2 Change	sr	*B*	SE B	β
(Block 1 – Control Variables)	.31**	.25**	.31**				
Ethnicity				-.06	-.24	.57	-.07
Education				.01	.01	.12	.01
(Block 2 – Intellectual Functioning)	.42**	.35**	.11*				
Shipley Score				.25	.11	.06	.34
(Block 3 – Simple Task)	.59***	.53***	.18**				
Digit Span Forward				.42	.59	.19	.51*
(Block 4 – Social Anxiety Predictor)	.60***	.51***	.00				
SIAS score				-.03	-.01	.02	-.04

Note. sr^2 = semi-partial correlation, which describes the percent variance accounted for by each predictor

*$p < .05$. ** $p < .01$. *** $p < .001$.

FIGURE 1

Baddeley's Working Memory Model